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Matteo Manfredi[a]*, Fabrizio Mele[a], Diletta Garrou [a], Jochen Walz[b], Jurgen J. Fütterer[c], Filippo Russo[d], Lorenzo Vassallo[d], Arnauld Villers[e], Mark Emberton[f], Massimo Valerio[g]

a. Department of Urology, University of Turin, San Luigi Gonzaga Hospital, Orbassano (Turin), Italy

b. Department of Urology, Institut Paoli-Calmettes Cancer Centre, Marseille, France

c. Department of Radiology and Nuclear Medicine, Radboud University Medical Centre, Nijmegen, The Netherlands

d. Department of Radiology, Candiolo Cancer Institute - FPO, IRCCS, Candiolo (Turin), Italy

e. Department of Urology, CHRU Lille, Université Lille Nord de France, Lille, France

f. Research Department of Urology, University College London, London, UK

g. Department of Urology, Centre Hospitalier Universitaire Vaudois, Lausanne, Switzerland

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Abstract

Multiparametric prostate MRI (mp-MRI) is an emerging imaging modality for diagnosis, characterization, staging, and treatment planning of prostate cancer. The technique, the report and its role in clinical practice has dramatically evolved during the past decade. Although the routine use of mp-MRI in the diagnostic pathway has not been established yet, almost all urological guidelines has underlined the potential role of mp-MRI in several aspects of prostate cancer management. Moreover, new sequences and scanning techniques are under evaluation to improve the diagnostic accuracy of mp-MRI.

This review presents an overview of mp-MRI, summarizing the technical conduct, the standardized reporting systems and its current role at various stages of prostate cancer management. Finally, this critical review reports also on the main limitations and the future perspectives.

Introduction

Prostate cancer (PCa) is the most common non-cutaneous cancer in men in Western countries, with an incidence > 200 per 100,000 men [1]. PCa is usually suspected in case of increased serum prostate-specific antigen (PSA) levels, and/or abnormal digital rectal examination (DRE). In these patients, histopathological confirmation is based on prostate biopsy. According to the recommendations of scientific societies - such as the European Association of Urology (EAU) - the standard sampling strategy is represented by transrectal ultrasound (TRUS)-guided biopsy with 12 cores spread in the peripheral zone of the gland in a systematic manner [2]. While this biopsy strategy is standardized and highly reproducible by urologists, it is prone to random and systematic error. This blind approach is unrelated to the location, the aggressiveness and the extension of the tumor; therefore, the odds of correct sampling are based on chance (random error). Further, some zones of the prostate are not sampled at all (systematic error). Whilst estimating the true extent of misclassification is challenging as many men do not undergo further confirmatory test, it has been estimated that false negative results are present in around 40% cases [3].

If prostate cancer is confirmed by prostate biopsy, the challenge is to assign a true risk-status to a given patient. Risk classification relies on prognostic factors including DRE, PSA and histopathological features, namely Gleason grade and disease burden. Men are finally counseled with respect to treatment options considering their risk-status, life expectancy and patients' preferences. It should be noted that in this standardized and expeditious pathway, there is something unique if we compare it to other solid malignancies: the absence of an accurate imaging method.

Multiparametric prostate MRI (mp-MRI) has demonstrated to be a useful imaging modality to interrogate the prostate gland. Although the routine use of mp-MRI in the diagnostic pathway has not been established yet, almost all urological guidelines has underlined the potential role of mp-MRI in several aspects of PCa management [2,4,5]. This review aims to present an overview on mp-MRI conduct, report and role in clinical practice, analyzing the main critical issues and underlining its future perspectives.

Technical conduct

The protocol for performing mp-MRI has been progressively ameliorated. For the purpose of this review, we should distinguish the hardware and the sequences.

With respect to the hardware, two field strength are available to perform prostate mp-MRI, 1.5 and 3.0 Tesla (T). Briefly, the main advantage of 3.0-T MRI is an increased signal to noise ratio (SNR) with an improved spatial and temporal resolution [6]. Conversely, the main disadvantage is the four-folds increase of power deposition compared to 1.5-T mp-MRI with an increased susceptibility and signal heterogeneity, due to shorter T2-weighted imaging (WI) and longer T1-WI relaxation [7]. Although some expert centres have similar performance using the two field strength, when available it is recommended to use a 3.0-T scanner [8].

The use of an external phased array coil across the pelvis with at least 16 channels is mandatory in prostate mp-MRI [8], whilst the need of an endorectal coil (ERC) is debated. When used, an ERC permits: 1) a greater SNR at any magnetic field strength

provided by the position of the coil close to the prostate; 2) the improvement in high spatial resolution imaging used in staging and in lower signal sequences; 3) the improvement in image quality in obese patients [8]. Conversely, the disadvantages are: 1) the discomfort caused by the coil placement, which can lead to poor patients' compliance; 2) the presence of magnetic susceptibility and motion-related artifacts; 3) potential gland deformation; 4) the increased costs, the additional time and human resources needed for coil placement and removal; 5) very rare complications (proctitis, rectal bleeding or erosion) due to air insufflation of the rectum [9].
Overall, the impact of an ERC seems to be more advantageous at 1.5-T compared to 3.0-T mp-MRI. Fütterer et al. showed in 81 consecutive patients undergoing 1.5-T mp-MRI before surgery, an improved staging accuracy, sensitivity and specificity when an ERC was used (83%, 64%, and 98%, respectively) compared to scans with no ERC (59%, 56%, and 62%, respectively). Moreover, the area under the curve (AUC) was significantly higher for ERC mp-MRI (AUC=0.74) compared to pelvic phased-array coil mp-MRI (AUC=0.57) [10]. However, de Rooij et al. reported, in a recent meta-analysis on 75 studies, including 9796 patients, that extra-capsular extension (ECE) sensitivity was not improved by the use of an ERC [11].
Conversely, the use of an ERC at 3.0-T mp-MRI is more debated: some authors reported a better staging due to improved image quality and tumor localization with ERC [12-14], whilst others demonstrated a similar accuracy regardless the use of an ERC [15,16].
Some authors compared 3.0-T scanners without ERC and 1.5-T scanners with ERC regarding local PCa staging, obtaining equivalent results in terms of accuracy for T3 stage detection: 72-73% at 3T vs. 70-73% at 1.5-T [6,17]. Further, Beyersdorff et al. suggested that image quality and delineation of PCa at 1.5 T with dual coil was superior to 3.0-T with no ERC [6]. In a recent study comparing 83 patients undergoing 1.5-T with an ERC and 83 patients undergoing 3.0-T mp-MRI, Shah et al. concluded that the images obtained with the 3.0-T scanner had similar image quality, but not better diagnostic performance, suggesting that an additional improve in technical aspects is possible [18].
Regarding the sequences, mp-MRI should be performed following the recommendations of the European Society of Urogenital Radiology (ESUR) guidelines [19].
The exam consists of morphological T2-weighted imaging (T2-WI) and functional techniques, namely diffusion-weighted imaging (DWI), and dynamic contrast-enhanced (DCE) MRI [19].
T2-WI have high spatial resolution, and are mainly employed to depict the zonal anatomy of the gland. PCa is usually identified as a low signal intensity area both in peripheral zone (PZ) and in transition zone (TZ) [20]. Data from a meta-analysis showed a sensitivity and specificity of T2-WI alone at 62% (95% Confidence Interval [CI] 55%-68%) and 77% (95% CI 71%-82%), respectively [21]. Even if some authors reported a high rate of false positive findings, especially in the TZ [22], T2-WI is considered the dominant sequence for the identification of PCa in the TZ by the updated PIRADS version 2. For the PZ, T2-WI is considered the secondary sequence in a decision making process after the results of DWI [8].

DWI is based on the Brownian motion in a tissue, which is the random diffusion of free water molecules. In prostatic tissue containing PCa, these movements are strongly inhibited. Therefore DWI sequences show a high signal intensity area on high b-value images (b > 1400 s/mm^2) that can be analyzed quantitatively by calculating an apparent diffusion coefficient (ADC) map [19]. In a recent meta-analysis, authors reported a pooled sensitivity and specificity of 62% (95% CI 61%-64%) and 90% (95% CI 89%-90%), respectively, for the detection of PCa in PZ with DWI [23]. Moreover, on ADC maps, an inverse correlation is reported between ADC values and Gleason score, even if the exact value of this correlation is still debated [24]. DWI is currently the dominant sequence for detection of PCa in the PZ [8]. For the TZ, DWI is considered the secondary sequence. In this case, when T2-WI is PIRADS 3, DWI may upgrade the assessment category to PIRADS 4. The only exception is the presence of round/oval, well-circumscribed, and encapsulated nodules with restricted diffusion, which are considered to be benign prostate hyperplasia and do not have to be assigned an assessment category [8].
DCE-MRI uses serial T1-weighted images after an intravenous bolus injection of gadolinium contrast to assess vascularity within the prostate. PCa commonly shows an early and intense uptake with rapid washout of contrast agent compared to benign tissue [19]. Results from a meta-analysis showed that the pooled sensitivity and specificity for detection of PCa with DCE-MRI was 55% (95% CI 45%-65%) and 85% (95% CI 81%-89%), respectively [25]. Even if recent guidelines include DCE to diagnose PCa [8], currently the additional value of this parameter is under debate. Some authors consider that the addition of DCE to T2-WI and DWI does not improve the detection of significant PCa, especially in the TZ where it can also reflect benign prostate hyperplasia [24,26], whilst others reported a significant improve in detection accuracy in PZ [27] and in TZ [22] adding DCE to DWI and T2-WI. The novel PIRADS version 2 has substantially reduced the importance of DCE over the final likelihood of presence of significant disease. However, when DWI results a PIRADS 3 in the PZ, a positive DCE may upgrade the assessment category to PIRADS 4 [8].
MRSI shows the relative concentrations of metabolites in PCa and benign prostate tissue [19]. This parameter is currently used in a research setting, and recent guidelines no longer suggests its clinical application [8].
In order to improve the accuracy of the exam, mp-MRI should be standardized not only with regard to technical equipment, examination protocols, and image acquisition and processing, but also with regard to reporting systems, as discussed in the next paragraph. Prostate mp-MRI is a challenging exam and there is a steep learning curve among radiologists for its interpretation. Some authors demonstrated significant inter-observer variability in interpretation of the exam, with different levels of reader's expertise being mandatory especially to reliably exclude and detect significant PCa [28].

Standardized reporting

Standardized reporting of mp-MRI is essential to facilitate communication between radiologists and urologists/radiation oncologists, with the overall aim to convert the radiological exam in a useful information for clinical decision-making, targeted biopsy

and eventually treatment planning. In most centres, two methods to report prostate mp-MRI are employed: subjective or semi-objective.
The subjective reporting system is based on scoring the likelihood of presence of significant disease at a lesion level detected on mp-MRI by using a 5-point Likert scale. The scale allows radiologists to score radiological lesions based on overall impression rather than on quantitative measures [29]. The score is obviously subjective and provides poor reproducibility, although in experts' hands, it might be at least as good as a standardized scoring system.
To provide a more standardized scoring system with the aim to improve MRI quality and reporting, the European Society of Urogenital Radiology (ESUR) proposed the Prostate Imaging Reporting and Data System (PIRADS), published in the ESUR guidelines in 2012 [19]. It is a 1 to 5 structured reporting scheme considering each of the different parameters (T2-WI, DWI, and DCE-MRI), providing a single PIRADS score which identifies from 1 to 5 the probability of presence of significant disease per lesion identified. In 2015, an updated version of PIRADS (PIRADS version 2) was published jointly to members of the American College of Radiologists (ACR) [8]. Among the novelties, as noted above, a dominant sequence was identified according to the prostate zone, whereas the impact of DCE findings was substantially reduced. Comparative studies between the two versions of PIRADS have provided conflicting results, with some authors showing an improved diagnostic performance for the assessment of suspicious lesions with PIRADS version 2 [30] whilst others reporting a superiority of PIRADS version 2 for the evaluation of TZ lesions, and of PIRADS version 1 for the evaluation of PZ lesions [31].
When comparing subjective and semi-objective reporting methods, Portalez et al. did not find a significant difference in terms of accuracy in 129 patients who underwent 1.5-T mp-MRI before targeted fusion biopsy [32]. In contrast, two other studies reported a more accurate interpretation of mp-MRI results using a subjective rather than a semi-objective scale. Rosenkatz et al. studied 55 patients undergoing 3.0-T mp-MRI and found that the reproducibility was similar for Likert and PIRADS version 1 scales in the PZ when comparing results of experienced radiologists, but it was higher for the Likert than for the PIRADS scale in the TZ [33]. In the study of Vachè et al. comparing the performances of two senior and one junior radiologists in reading 215 mp-MRI, the Likert score resulted in more accurate characterization of the likelihood of malignancy of mp-MRI lesions when compared to PIRADS version 1 or to another semi-objective scale (the "morphology-location-signal intensity" scale) [34]. As expected, in almost all studies, the results were dependent on radiologist expertise. To date, there are no available studies comparing PIRADS version 2 against Likert scale. As stated, in PIRADS version 2, standardized reporting should provide the volume of the prostate gland, as well as the location, the largest dimension (or volume) and the sector of up to four suspicious lesions with a PIRADS assessment category of 3 to 5. Among them, the index intraprostatic lesion should be identified. Moreover, findings suspicious of ECE, SVI, or lymph node invasion should be reported [8].

Clinical use

Common indications for mp-MRI are: (1) lesions detection and localization; and (2) local staging of PCa (Figure 1). Recently, two other indications, derived from the two previously reported, have been progressively adopted: (3) selection and monitoring of patients on active surveillance; (4) guide for targeted biopsies.

Detection and localization of PCa

With respect to detection, considering the detection rate of any grade PCa, Tan et al. reported in a meta-analysis a pooled sensitivity and specificity of 57% (95% CI 52%-62%) and 89% (95% CI 83%-94%), respectively. The calculated AUC for the combination of T2-WI, DWI and DCE-MRI was 72% (95% CI 67%-77%) [25]. In a recent systematic review, the authors analyzed 12 papers to determine the diagnostic accuracy of mp-MRI in the detection of clinically significant PCa. The accuracy, sensitivity, and specificity were 44%-87%, 58%-96%, and 23%-87%, respectively. Of note, prostate biopsy or radical prostatectomy specimens were used as the reference test, and various definitions of clinically significant PCa were employed. This variability might explain the wide confidence of intervals of the diagnostic performance [35].

With respect to localization, Le et al., in a study looking at the detection of PCa at a single lesion level, found that 64% men had multifocal tumors on prostatectomy specimens. In these, the index lesion was detected by mp-MRI in 77% cases [36]. Recently, mp-MRI has been also proposed at the outset of the diagnostic pathway. A randomized controlled trial (RCT) supported the potential role of mp-MRI as a triage test in the diagnostic pathway of biopsy-naïve patients with suspected PCa. The population consisted of patients with PSA levels up to 15 ng/ml and negative DRE, with two groups randomized in prebiopsy mp-MRI versus standard biopsy. PCa was diagnosed in 50.5% of patients in the mp-MRI group, with 87% of cases being clinically significant, whilst in standard group the overall detection of PCa was 29.5% with significant PCa detected in 93.9% cases [37]. Previously, other RCTs had shown conflicting results [38,39]. Is noteworthy that the results of these comparative studies depend on the definition of PCa significance, and that it is methodologically questionable to apply the same definitions for MRI-targeted and standard biopsies. To conclude, in all studies the accuracy of mp-MRI vary with characteristics related to PCa, such as GS or tumor volume [40].

Local staging of PCa

Several studies have shown that mp-MRI is a useful tool to predict ECE. This information is important for correct patients' management. Somford et al. calculated that overall staging accuracy of mp-MRI in terms of ECE detection was 73.8%. The sensitivity, specificity, positive predictive value and negative predictive value were 58.2%, 89.1%, 84.1% and 68.3%, respectively. Moreover, on multivariate analysis, mp-MRI prior to radical prostatectomy resulted the best preoperative predictor of ECE, reaching an odds ratio over 10 [41]. Soylu et al. reported a study including 131 patients undergoing 1.5-T mp-MRI with an ERC before radical prostatectomy, interpreted by two radiologists. Sensitivity and specificity for detection of SVI were 52-59% and 93.1-93.6%, respectively [42]. Finally, a recent meta-analysis confirmed that mp-MRI has high specificity but poor sensitivity for local PCa staging [11]. The pooled

sensitivity and specificity for ECE, SVI, and stage T3 were 57% (95% CI 49% - 65%) and 91% (95% CI 88% - 93%), 58% (95% CI 47% - 68%) and 97% (95% CI 95% - 98%), and 61% (95% CI 54% - 67%) and 88% (95% CI 85% - 91%), respectively. With regard to the detection of SVI, the use of an ERC showed an increased sensitivity, as opposite to the detection of ECE, as reported above.
While some may argue that local staging has little influence on clinical management in most cases, the information provided by the MR might be used for treatment planning. Based on this information, the surgeon might be able to preserve key functional structures - such as neurovascular bundles - in order to maximize genito-urinary function with no impact on the oncological outcome. Indeed, mp-MRI has been shown to improve the decision making with respect to the margin of excision. McClure et al. prospectively evaluated 104 consecutive men with PCa undergoing mp-MRI prior to radical prostatectomy. The planned extent of resection was determined after review of the mp-MRI report. In this study, preoperative MRI changed the surgical strategy in 27% patients [43].
Park et al. included in a study 353 men with PCa and underwent mp-MRI prior to robotic assisted radical prostatectomy. After review of the MRI reports, imaging significantly improved the clinician's decision making changing the initial surgical plan in 26% patients. The appropriateness resulted 91% for the patients with a change to more conservative surgery [44].
In radiotherapy, inaccurate local staging might lead to poor oncological outcome because standard target volumes may not adequately cover all malignant lesions. Retrospective data in radiotherapy series showed that by using mp-MRI as a staging tool, target coverage changed in up to 20% cases [45].
In a recent meta-analysis, von Eyben et al. evaluated the role of functional imaging in identifying a dominant intraprostatic lesion which could be treated with a radiotherapy boost to an ultrahigh dose level without increased toxicity. They concluded that 94% studies used mp-MRI as the functional imaging study to identify and characterize intraprostatic lesions, allowing radiation oncologists to treat with an elevated dose the dominant lesions [46].

Selection and monitoring of patients for active surveillance
Active surveillance (AS) is a treatment strategy for well selected patients harboring low risk PCa. Protocols for AS, which rely on PSA, PSA-related markers and TRUS biopsy, have often been criticized in light of a misclassification rate reaching 50%. In this context, the ability of mp-MRI to selectively detect high grade and large volume PCa is very useful in order to discriminate significant from insignificant PCa with the overriding aim to decrease the rate of patients misclassified with standard diagnostic tools [47].
Imaging has two potential roles in AS: 1) to confirm low risk disease; 2) to exclude tumor progression during follow up.
In candidates for AS, some authors reported a good correlation between mp-MRI and pathologic findings. In a retrospective study evaluating 133 patients undergoing 3-T mp-MRI prior to radical prostatectomy, surgical specimens were retrospectively evaluated to classify patients as good or poor candidates for AS. mp-MRI had an overall

accuracy of 92% in assigning true risk status, and importantly, proved to be substantially useful when added to classic classification systems, namely D'Amico risk classification (p=0.005) [48]. With respect to the assessment of PCa aggressiveness, many authors reported that low ADC values are associated with higher Gleason scores [49], concluding that DWI scores may be used to improve risk-assessment in PCa [50]. We underline that the topic still remains controversial due to the wide range of DWI scores and relative CI found in correlation with each Gleason category in these studies. In a recent study, the assessment of PCa aggressiveness was retrospectively evaluated by the use of DWI and DCE-MRI in 158 men underwent 3T mp-MRI and subsequent radical prostatectomy, using surgical specimens to identify 195 PCa foci and to calculate the per-lesion ADC and K(trans) values. The ADC values were significantly associated with all GSs, whilst the K(trans) values showed moderate correlation only for more aggressive tumors. The combination of the two parameters showed a better performance in assessing tumor aggressiveness [51].
mp-MRI could also be very useful in the follow up of patients under AS. Schoots et al. reported in a systematic review focused on this topic that the use of a mp-MRI-targeted biopsy as a confirmation biopsy resulted in a reclassification rate of 33% according to PRIAS criteria [52].
On the other hand, Robertson et al., in a study conducted on 107 3D-models of whole-mount radical prostatectomy specimens used for computer simulations, concluded that MRI-targeted biopsy will increase risk attribution from 24 to 74% if criteria from randomized biopsy (e.g., cancer core length and positive cores rate) were applied [53].
Few published studies are available on how to monitor patients under AS incorporating mp-MRI. Preliminary recommendations were recently published by the European School of Oncology Task Force - the PRECISE recommendations. These were designed to help clinicians in evaluate changes in mp-MRI findings over time in the follow up of patients under AS [54]. The main advice is to include the use of a checklist items for reporting a cohort of men on AS, including the report of the index lesion size at baseline and at each follow-up mp-MRI. Moreover, radiologists should assess the likelihood of change in size or in lesion characteristics over time.

Guide for targeted biopsies
mp-MRI allows the clinician to perform targeted biopsy. This has been proven to better characterize suspicious lesions, due to the centered core and the higher cancer involvement per core, and to detect more high grade cancers [55].
mp-MRI could be used to guide a prostate biopsy in three ways: in-bore targeted biopsy, MRI-TRUS cognitive registration, and MRI-TRUS software-based registration. In-bore MRI - which means in the MR suite - targeted biopsy has an excellent detection rate, and performs better than random biopsy [56]. However, the spread of this technique beyond few centres has been limited in light of cost, time and resource issues [57]. The simplest strategy is the cognitive registration, which means the operator directs visually targeted needles to the suspicious regions described on mp-MRI. Although this approach seems to be more accurate compared to random biopsy, it is poorly reproducible and relies on expert operators [58].

MRI-TRUS software-based registration is probably the most reproducible targeted biopsy strategy, combining the diagnostic accuracy of mp-MRI with the accessibility of TRUS and the guidance of a fusion software [59].
Beyond the fusion strategy, MRI targeted biopsies have a definitive role in patients with previous negative biopsy [3].
For instance, Sonn et al. published a paired cohort study including 105 men with prior negative biopsies. MRI-US fusion targeted biopsy detected 21.7% men with significant PCa whilst a new standard biopsy detected 14.7% [60].
In biopsy-naïve patients the role of mp-MRI is more debated: to offer mp-MRI to all men at risk has relevant cost implications, and cost/ effectiveness has not been rigorously quantified. As noted above, some authors reported better results in targeted biopsies when compared to standard approach in this setting [37]. Siddiqui et al. in a study with 1003 men undergoing both MRI-US fusion targeted and standard biopsy, conducted a subanalysis of 196/1003 (20%) biopsy-naïve patients. They concluded that MRI targeted fusion biopsy limited over-detection of clinically insignificant PCa and provided greater detection of clinically significant PCa than standard biopsy [61]. It is noteworthy to highlight that authors limited the study to patients with positive mp-MRI; this represents a relevant work-up bias. In other words, the main criticism of this study and of many studies reporting on MRI targeted biopsy is that the findings in the population of men testing negative to mp-MRI are often omitted.

Limitations

Even if several studies have demonstrated the high diagnostic performance of mp-MRI in detecting PCa, the imaging test is not perfect and some tumors, mainly low grade low volume lesions, might be missed or misclassified. The detection of a discrete malignant lesion actually depends on many parameters: size, grade, and relative tumor content.
With respect to the size and grade, De Visschere et al. reported an underdetection rate at 14.9%, but all these tumors had low volume and/or low GS [62]. As reported above, Le et al. in a study looking at the detection of PCa at a single lesion level, found that although mp-MRI sensitivity increased for higher-grade PCa, 28% of GS 7 PCa and 28% of PCa of >1 cm in diameter were missed. Moreover, non-index tumor detection was significantly lower, even in the few cases of high-grade PCa [36]. This has important implications for tissue preserving approaches - focal therapy - and for treatment planning, as the MRI guidance might not be fully reliable.
With respect to the relative tumor content, Langer et al. reported in a study considering 28 prostate lesions, that PCa with more than 50% of the area occupied by benign tissue, had T2-WI images and ADC values similar to normal tissue [63].
Even if a triage test skewed towards the detection of exclusively high risk disease - such as mp-MRI - might substantially improve the unfavorable risk to benefit ratio patients with PCa have to face at present, actually a major limitation of mp-MRI is the absence of standardization and quality control among different radiologists and centers. Branger et al. recently published a retrospective analysis of 101 patients who underwent radical prostatectomy and who had a preoperative negative mp-MRI. Final

pathology
showed that 55.9% had a main tumor volume of ≥0.5, 16.9% had ECE, 13.8% had primary Gleason pattern 4, and 47.5% had secondary Gleason pattern 4 or 5 [64]. These results support the need of a specialised uroradiologist and expert centers, before mp-MRI can be adopted as a standard imaging tool across the board.

Future perspectives

Despite recent developments in mp-MRI, the field is in continuous evolution. The diagnostic performance of mp-MRI might be further ameliorated with the introduction of novel technologies, mainly impacting on sequences and higher field strength.
With respect to T2-WI, the challenge is to obtain high-quality images without motion artifacts [65,66]. This sequence is typically performed using a fast spin-echo technique that often requires four minutes or more to acquire images in a given plane. Thus, T2-WI is prone to artifacts from bulk patient motion, peristalsis of pelvic bowel loops and motion of the prostate itself. An alternative approach for reducing, if not eliminating, motion artifact is the use of new T2-WI sequences, similar in technical approach, developed from the MR scanners companies, namely PROPELLER (General Electric Healthcare, USA), BLADE (Siemens Healthcare, Germany), and MultiVane (Philips Healthcare, Netherlands). In this review, we will discuss
the PROPELLER (Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction) technique that was developed by Pipe in the late 1990s [67]. The basic idea was to sample k-space (which contains the highest signal amplitude and contributes most to image contrast) in a rotating fashion using a set of radially directed strips or "blades". The center of k-space is oversampled, meaning that the signal-to-noise and contrast-to-noise ratios will be high. Oversampling in this region also provides redundancy of information, meaning that the data for new each blade can be compared to the data from previous blades for consistency. If the patient moves between blades, the data for the second blade can be corrected (or even completely discarded) based on how anomalous its central information appears [65]. The PROPELLER reconstruction algorithm involves several steps: 1) phase correction for each blade to assure its point of rotation is exactly at the center of k-space; 2) corrections for bulk in-plane rotation and in-plane translation of the object; and 3) correlation-weighting to minimize the data from blades containing motion or displacement errors [67]. Current 2D versions of PROPELLER correct only for in-plane motion, but 3D versions may overcome this limitation in the future. This sophisticated reconstruction process does take some additional time after the scan is completed, and with our current computer hardware an additional delay of ≥ 15 seconds may be required to process a large data set before the next sequence can begin [66].
With respect to DWI, in the PI-RADS version 2 this sequence plays an important and increasing role to identify and characterize PCa [8]. Recent innovations have significantly improved the quality of this sequence. As opposite to conventional full-Field of View (FOV) slice-selective excitation in echo planar imaging, the spatially selective 2D radiofrequency (RF) excitation (e.g. FOCUS DWI, General Electric Healthcare, USA) is selective in either slice and phase encoding direction. This

technique reduces blurring by excluding sources of artifacts (magnetic field non-homogeneity, bowel movement) that are outside the region of interest [68]. The reduced FOV sequence significantly decreases the image distortion, the rectal wall susceptibility artifact and the ERC artifacts in the apex region and provide significantly higher contrast between tumor and healthy tissue. The spatially selective 2D RF excitation shows great promise for improving DWI quality thereby potentially improving the detection and assessment of PCa volume and grade [68].

With respect to higher field strength, 7.0-T MRI have been developed for research purpose. They offer the possibility to use contrast mechanisms that have not been reliably performed at 1.5 and 3.0-T [69,70] such as arterial-spin labeling and multinuclear imaging. However, higher field strength come with several limitations, like inhomogeneous transmit fields, a higher specific absorption rate and, currently, extensive contraindications for patient scanning [71]. Moving to an ultra-high magnetic field strength may have clinical advantages because of an intrinsic increase of the SNR, which in theory could be used to increase spatial resolution or reduce imaging time [72]. Moreover, imaging at 7.0-T opens up the search for new, previously unreachable biomarkers for prostate cancer management. For example, phosphorus (31P) spectroscopic imaging can be performed at clinically relevant spatial resolutions and imaging times [73]. Future studies will be aimed at assessing the advantages and disadvantages of 7.0-T MRI over lower field strengths in light of clinical applications.

In conclusion, the adoption of mp-MRI in clinical practice has the potential to improve both the diagnostic and the therapeutic management of PCa. In expert centres, mp-MRI is already an essential tool for decision making. Urological guidelines are increasingly incorporating mp-MRI at various stages, from triage test to treatment guidance. Although the test is not perfect, the progress in mp-MRI conduct as well as the standardization of reporting schemes will further ease the dissemination of this imaging test.

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